Characterization of Biological Types of Cattle (Cycle IV): Carcass Traits and Longissimus Palatability[1,2]

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ABSTRACT: Carcass and longissimus thoracis palatability traits from 888 steers obtained from mating Hereford and Angus cows to Hereford or Angus (HA), Charolais (Ch), Gelbvieh (Gb), Pinzgauer (Pz), Shorthorn (Sh), Galloway (Gw), Longhorn (Lh), Nellore (Ne), Piedmontese (Pm), and Salers (Sa) sires were compared. Data were adjusted to constant age (426 d), carcass weight (324 kg), fat thickness (1.2 cm), fat trim percentage (23%), and marbling (small^{00}) end points. At a constant age of 426 d, carcasses from Ch steers were heaviest (P < .05) and Gw and Lh carcasses were lightest (P < .05). Adjusted fat thickness was greatest (P < .05) on carcasses from HA and least (P < .05) on carcasses from Ch, Gb, Lh, and Pm steers. USDA numerical yield grades were lowest (P < .05) for carcasses from Pm and highest (P < .05) for carcasses from HA, Ne, and Sh steers. Marbling scores were highest (P < .05) for carcasses from HA, Pz, and Sh and lowest (P < .05) for carcasses from Ch, Ne, and Pm steers. Longissimus thoracis from Pz had a lower (P < .05) shear force than that from all other breeds except HA, Gb, and Pm. Longissimus thoracis of carcasses from Ne steers was least (P < .05) tender. Adjustment of traits to various end points resulted in some changes in sire breed differences depending on the end point and the trait being considered but had little effect on palatability traits. Carcasses from Pm-sired steers provided the most desirable combination of carcass and longissimus palatability traits.

Key Words: Beef, Breeds, Carcass, Palatability, Tenderness

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Introduction

The first three cycles of the Germplasm Evaluation (**GPE**) program at the Roman L. Hruska U.S. Meat Animal Research Center (**MARC**) characterized 16 breeds representing several biological types of cattle. Carcass and longissimus palatability traits from the first three cycles were reported by Koch et al. (1976, 1979, 1982b). Breed differences in production traits are important genetic resources for improving beef production efficiency and meat composition and quality. No one breed excels in all traits that are important to beef production. Diverse breeds are required to exploit heterosis and complementarity through crossbreeding and to match genetic potential with diverse markets, feed resources, and climates. Evaluation of carcass traits and meat palatability from different breeds or breed crosses is important in determining the potential value of alternative germplasm resources for profitable beef production. This paper reports on Cycle IV (which includes five breeds repeated from earlier cycles and six new breeds) of the GPE program that characterizes cattle breeds representing diverse biological types for carcass and longissimus palatability traits that affect the quantity, quality, and value of production.

Materials and Methods

Animals

Hereford or Angus dams were mated by AI to 30 Angus and 32 Hereford, 29 Longhorn, 24 Piedmontese, 31 Charolais, 29 Salers, 31 Galloway, 22 Nellore, and 26 Shorthorn bulls to produce 593 steer calves. Following an AI period of about 45 d, 8 Hereford, 11 Angus, 10 Charolais, 18 Gelbvieh, and 16 Pinzgauer

[1]Mention of trade names, proprietary products or specific equipment does not constitute a guarantee or warranty of the product by the USDA and does not imply its approval to the exclusion of other products that also may be suitable.

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Table 1. Number of sires used per breed and number of steers in each breed of sire × dam subclass[a]

		Dam breed and number of steer progeny		
Sire breed	Number of sires	Hereford	Angus	Total
AI Hereford	17	—	20	20
CU Hereford	8	—	24	24
AI Angus	12	14	—	14
CU Angus	11	27	—	27
AI Charolais	23	17	26	43
CU Charolais	10	23	20	43
CU Gelbvieh	18	55	50	105
CU Pinzgauer	16	56	40	96
Shorthorn	24	45	50	95
Galloway	26	31	44	75
Longhorn	28	43	49	92
Nellore	22	49	48	97
Piedmontese	20	34	46	80
Salers	23	38	39	77
Total	258	432	456	888

[a]The Hereford and Angus sires are new (born 1982–84) relative to the original Hereford and Angus sires (born 1963–70) used in Cycles I to III of the Germplasm Evaluation project. Clean-up (CU) sires also represent "new" sires, but have not had as intensive a selection as the AI sires; thus, results from their progeny were reported separately. Purebred Hereford and Angus progeny were not included to avoid confounding sire breed effects with heterosis effects.

bulls (1 or 2 bulls per breed per year) were used for natural service clean-up matings in single-sire breeding pastures to produce 295 steer calves. These breeds were used in clean-up matings to facilitate comparisons to previous cycles (Table 1). Clean-up and AI matings produced 888 steer calves in five calf crops (1986 to 1990). Only data from the Hereford × Angus and Angus × Hereford (**HA**) matings are presented (purebred Hereford and purebred Angus were not included) to avoid confounding sire breed effects with heterosis effects. The Hereford and Angus sires are "new" (born 1982 to 1984) relative to the original Hereford and Angus sires (born 1963 to 1970) used in Cycles I to III of the GPE. Clean-up (**CU**) sires also represent "new" sires but have not had the benefit of as intensive selection for growth and milk EPD as the AI sires; thus, data for their progeny are reported separately from data for AI sires. In cooperation with seedstock breeders and commercial AI organizations, young sires (< 2 yr old) identified as herd sire prospects, based on EPD for growth, were selected to represent the Hereford, Angus, Charolais, Shorthorn, Gelbvieh, Salers, and Pinzgauer breeds. Sires used to represent the Longhorn and Galloway breeds included some young and some older established bulls identified in cooperation with breed associations and seedstock breeders, but without benefit of EPD. Sires representing the Nellore breed included all sires imported into the United States at that time (1985). Sires (< 2 yr old) used to represent the Piedmontese breed were identified in cooperation with seedstock breeders in the United States and Canada, and commercial AI organizations, but without benefit from EPD.

Calves were born in the spring, beginning in March each year. Male calves were castrated within 24 h of birth. Calves were creep-fed whole oats from mid-July or early August until weaning in early October. Calves averaged about 155 d of age at weaning. Steers were fed separately by sire breed in replicated pens for about 272 d (ranged from about 240 to 302 d). The steers were slaughtered serially each year, in three slaughter groups spanning 56 d, or four slaughter groups spanning 63 d. A growing diet containing 66% corn silage, 22% corn, and 12% supplement (dry matter basis) was fed until steers weighed about 320 kg. A finishing diet containing 25% corn silage, 70% corn, and 5% supplement was fed from about 320 kg to slaughter.

Final unshrunk live weights were obtained 1 wk before slaughter. The steers were slaughtered in a commercial beef processing facility. Carcass sides were electrically stimulated within 45 min postmortem with the following sequence: 68 V (3 s on, 3 s off), 70 V (2 s on, 3 s off), 70 V (2 s on, 3 s off), 70 V (2 s on, 3 s off). Carcasses were spray-chilled with a mist of 2°C water for 30 s every 5 min during the first 12 h of chilling. After a 24-h chill at 0°C, USDA yield and quality grade data were obtained by trained USDA-ARS personnel (USDA, 1989). The percentage of carcasses qualifying for USDA Choice quality grade or higher was recorded as a 0,1 variable. The right side of each carcass was returned to the meat laboratory at MARC. Four 2.54-cm-thick ribeye steaks were cut from the IMPS #112 ribeye roll between the 8th and 12th ribs and vacuum-packaged. The steak from the 11th rib was used for Warner-Bratzler shear force determination and the two steaks from the 8th to 10th ribs were used for sensory evaluation. The steak from the 12th rib was used for raw proximate analysis of the longissimus after trimming all fat and epimysium. The shear-force steak was used for cooked proximate analysis of the longissimus. The steaks were stored at 2°C until 7 d postmortem then frozen at –20°C and stored frozen for 3 to 5 mo. Frozen steaks were thawed at 3°C for 24 h, broiled on Farberware Open Hearth electric boilers (Farberware, Bronx, NY) to 40°C internal temperature, then turned and broiled to a final internal temperature of 70°C. The shear-force steak was trimmed before cooking so that only the longissimus thoracis was cooked. The sensory steaks were cooked as ribeye steaks and trimmed after cooking so that only the longissimus thoracis remained. Only the longissimus thoracis from the steaks was evaluated.

Warner-Bratzler Shear Force

After cooking, longissimus thoracis steaks were chilled for 24 h at 3°C, and then six cores 1.27 cm in diameter were removed parallel to the muscle fiber orientation and sheared once each on an Instron Universal Testing Machine (Instron, Canton, MA) with a Warner-Bratzler shear attachment, 50-kg load cell, full-scale load setting 10, and crosshead speed of 5 cm/min.

Trained Sensory Evaluation

Cooked longissimus thoracis was cut into 1-cm × 1-cm × steak thickness cubes. Three cubes were served warm to each panel member. An eight-person sensory panel trained according to Cross et al. (1978) evaluated cooked steaks for tenderness, juiciness, and beef flavor intensity on an 8-point scale (8 = extremely tender, juicy, or intense; 1 = extremely tough, dry, or bland). Five steaks were served in each of two sessions (15 min between sessions) 3 d a week.

Proximate Composition Analyses

Raw and cooked longissimus thoracis steaks were ground through a .48-cm plate. Duplicate 100-g random samples were taken, wrapped in cheesecloth, and frozen at –30°C. Moisture content was determined after samples were thawed and subjected to oven drying at 100°C for 24 h. Total lipids were obtained on dried samples by diethyl ether extraction. Protein content was calculated by difference.

Statistical Analyses

Data were analyzed by least squares, mixed-model procedures (Harvey, 1985) considering appropriate fixed effects (sire breed, dam breed, sire breed × dam breed, birth year); random effects (sire nested within sire breed) to test sire breed; and residual variance to test other fixed effects.

In addition, linear regression of traits on differences in weaning age (due to differences in birth date) and differences in days fed (due to serial slaughter design) were fitted simultaneously with the main effects. The regression of traits on days fed provides a method of adjusting the age-constant sire breed means to alternative end points. The regressions were used for estimating values that would have been obtained if all animals in a sire breed had been fed fewer or more days until the breed group average reached a given end point (the mean for this experiment) with regard to age (426 d), carcass weight (324 kg), fat thickness (1.2 cm), fat trim percentage (23%; when cuts were trimmed to 0 cm of fat cover), or marbling (Small^{00}) following procedures used in previous cycles of GPE (Koch et al., 1979, 1982b). Each end point has merit for specific applications, but no one basis of comparison is suitable for answering all questions related to differences among sire breeds. Age-constant contrasts measure the impact of overall growth rates to selected ages. Weight-constant contrasts accentuate the differential growth rates of lean, fat, and bone in relation to differences in maturity. Fatness end points are useful for comparisons at similar physiological maturities. The percentage fat trim end point should be a more accurate comparison at a constant degree of fatness than fat thickness; however, fat thickness provides for comparisons to other experiments and other industry applications when fat thickness, but not fat trim percentage, is available. Comparisons at marbling end points are important because of the current emphasis on USDA Choice quality grade as a marketing end point.

Regressions were calculated for each sire breed. Sampling errors of regression coefficients were large, and differences among sire breed coefficients were not statistically significant. Therefore, a common regression (average of all sire breeds) would be one alternative to using the separate sire breed regressions. However, significant differences among age-constant means for sire breeds provide evidence that progeny of different sire breeds grew at different rates. The average regression represents the average growth rate. Therefore, the average regression over all sire breeds was modified by a proportionate adjustment of the sire breed mean to the general mean (μ) as follows:

$$\hat{y}_i = \frac{y_i}{y_\mu}[y_\mu + b_\mu (D - \bar{d})],$$

where $\hat{y}_i$ is the adjusted mean of the ith sire breed, y_i is the age-constant least squares mean of the ith sire breed, y_μ is the least squares mean for all sire breeds, b_μ is the average regression coefficient over all sire breeds, D is the number of days fed required to reach a given end point, and $\bar{d}$ is the average number of days fed (272.4).

The number of days fed required to reach a given end point can be derived by substituting the end point (e.g., 324 kg in the case of constant carcass weight) in the equation for $\hat{y}_i$ and solving for *D*. The derived *D* then is used in the equation for all traits other than that end point (carcass weight in this case).

Results and Discussion

The analysis of variance indicated that sire breed and year were significant sources of variation for all traits (Table 2). Dam breed was a significant source of variation for all traits except tenderness and juiciness. Sire breed × dam breed interaction was a significant source of variation for live and carcass weights, adjusted fat thickness, and yield grade. Linear regressions of weaning age and days fed were significant for most traits.

Carcass Traits

Sire breeds differed significantly in growth rate. Final live and carcass weights were heaviest for AI Charolais-sired steers, followed by CU Charolais-, AI HA-, Shorthorn-, Salers-, and CU Gelbvieh-sired steers at a constant age of 426 d (Table 3). At a constant fat thickness, AI Charolais-sired steers were heaviest, then Piedmontese-sired steers, followed by CU Gelbvieh-, Salers-, and CU Charolais-sired steers. Similar sire breed differences occurred at the fat trim end point, except that Piedmontese-sired steers were heavier than AI Charolais-sired steers. At a constant marbling degree, CU Charolais-sired steers were heaviest, followed by AI Charolais-, Nellore-, Salers-, and then Piedmontese-sired steers. Longhorn-sired steers were the lightest at all end points except for Galloway-sired steers at a constant fat thickness.

Dressing percentage tended to be greater for Nellore- than for Piedmontese-sired steers at age-, weight-, and marbling-constant end points. However, Piedmontese-sired steers had higher dressing percentage than Nellore-sired steers at constant fat thickness or fat trim end points. Both had higher dressing percentages than all other sire breeds at all end points. The CU Pinzgauer-sired steers tended to have the lowest dressing percentage at age- and weight-constant end points, but CU HA tended to have the lowest dressing percentage at constant fat thickness or fat trim end points.

Piedmontese-sired steers had the largest longissimus area, followed by carcasses from AI Charolais-sired steers at all end points. The CU HA-, Longhorn-, Shorthorn-, and AI HA-sired steers tended to have the smallest longissimus areas, regardless of end point.

Adjusted fat thickness was highest for carcasses from AI HA-, followed by CU HA-sired steers than for Nellore-, Shorthorn-, and Galloway-sired steers at constant age. Piedmontese-, AI Charolais-, CU Gelb-

Table 2. Analysis of variance

		Mean squares												
Source	df	Live weight, kg	Hot carcass weight, kg	Dressing percentage	Adjusted fat thickness, cm	Longissimus area, cm	Kidney, pelvic, and heart fat, %	USDA Yield grade	Marbling score	USDA Choice, %	Shear force, kg	Tenderness rating	Juiciness rating	Beef flavor intensity rating
Sire breed (SB)	11	53,809*	23,033*	52.8*	3.9*	1,542*	2.3*	11.3*	27,755*	12,693*	19.1*	5.9*	.83*	.26*
Sire (Sire breed)	213	1,845*	768	2.8	.2*	68*	.4*	.6*	5,370*	2,182*	2.6*	.7*	.14	.08*
Dam breed (DB)	1	44,380*	30,032*	71.6*	5.5*	279*	3.1*	10.8*	106,376*	83,871*	.4	1.2	.56	.60*
Year (Y)	4	36,060*	11,001*	78.5*	2.3*	502*	3.0*	2.3*	16,511*	6,893*	16.7*	2.0*	.43*	.58*
SB × DB	11	3,115*	1,284*	2.0	.4*	43	.2	.5*	1,866	1,340	.9	.3	.24	.10
b1 (weaning age)	1	111,734*	52,552*	15.3*	1.8*	747*	1.5*	4.5*	16,568*	2,718	22.0*	.3	.00	.01
b2 (days fed)	1	633,052*	332,516*	244.6*	32.3*	986*	41.1*	103.0*	135,192*	34,750*	45.1*	.7	3.68*	.42*
Residual	645	1,540	673	2.7	.1	40	.3	.3	3,008	1,674	1.9	.5	.16	.07

*$P < .05$.

vieh- and Longhorn-sired steers had the lowest adjusted fat thickness at constant age. At constant weight, CU HA-, AI HA-, and Galloway-sired steers had the highest and AI Charolais- and Piedmontese-sired steers had the lowest adjusted fat thickness. At constant marbling, Nellore-sired steers had the highest fat thickness, followed by CU Charolais-sired steers. Shorthorn-sired steers, then CU HA- and CU Pinzgauer-sired steers, followed by AI Charolais-, Longhorn-, and Piedmontese-sired steers, had the lowest fat thickness at constant marbling. At constant fat trim percentage, Piedmontese-sired steers had the highest fat thickness, then CU Charolais-sired steers, followed by CU Gelbvieh- and Galloway-sired steers. Shorthorn- and Longhorn--sired steers tended to have the lowest fat thickness at constant fat trim.

At constant age, percentage of kidney, pelvic, and heart (**KPH**) fat tended to be lower in carcasses from Piedmontese-, CU HA-, Galloway-, CU Gelbvieh-, and AI HA-sired steers. At constant weight, percentage of KPH fat tended to be lower in carcasses from Piedmontese-, AI Charolais-, AI HA-, CU Gelbvieh-, CU HA-, and CU Charolais-sired steers, and highest in carcasses from Longhorn-sired steers. At constant fat thickness, AI HA- and CU HA-sired steers had the highest percentage of KPH fat, Galloway-sired steers were intermediate, and Charolais- and Longhorn-sired steers had the most KPH fat. At constant marbling, Nellore-sired steers had the higher percentage KPH fat, followed by CU Charolais-sired steers, and CU HA- and Shorthorn-sired steers had the lowest percentage KPH fat. At constant fat trim, Piedmontese-sired steers had the highest percentage of KPH fat and AI HA- and CU HA-sired steers had the lowest percentage of KPH fat.

At constant age, numerical USDA yield grade was lowest for carcasses from Piedmontese-sired steers and highest for carcasses of AI HA-, CU HA-, Nellore-, and Shorthorn-sired steers. At constant age, the mean yield grade of 3.84 for AI HA-sired steers resulted in a relatively high percentage (32.4%) of carcasses with a yield grade 4.0 or greater. Even for CU HA-, Nellore-, and Shorthorn-sired steers, a significant percentage of carcasses had a yield grade 4.0 or greater (31.9, 26.0, and 27.8%, respectively). At constant weight, carcasses from Longhorn-, CU HA-, AI HA-, Galloway-sired steers had the highest yield grades and Piedmontese- and AI Charolais-sired steers had the lowest yield grades. At constant fat thickness, there was little variation among sire breeds in yield grades, although Piedmontese- and Shorthorn-sired steers had lower yield grades than most other sire breeds. At constant marbling, carcasses from Nellore- and CU Charolais-sired steers had the highest yield grades and carcasses from Shorthorn-sired steers had the lowest yield grades, followed by Piedmontese-, CU HA-, and CU Pinzgauer-sired steers. At constant fat trim, carcasses from CU Charolais-, Piedmontese-, CU Gelbvieh-, and AI Charolais-sired steers had the highest yield grades, and Shorthorn- and Longhorn-sired steers had the lowest yield grades.

At constant age, marbling score was higher in carcasses of Shorthorn-sired steers than in carcasses of all breeds except CU HA-, AI HA-, and CU Pinzgauer-sired steers. Marbling scores were lower in carcasses of Nellore-, CU Charolais-, and Piedmontese-sired steers than in those of most other breeds at a constant age. At a constant weight, CU HA-, Shorthorn-, and Longhorn-sired steers had the highest marbling scores. At a constant fat thickness, Shorthorn-sired steers, followed by CU Pinzgauer-, Piedmontese-, AI Charolais-, and Longhorn-sired steers, had the highest marbling scores. However, at a constant fat trim, Piedmontese-sired steers had the highest marbling score, followed by CU Pinzgauer-, and AI Charolais-sired steers. Nellore- and CU Charolais-sired steers tended to have the lowest marbling scores regardless of end point. Sire breed differences for the percentage of carcasses grading USDA Choice at each end point were similar to marbling differences. The percentage of carcasses grading USDA Standard was relatively low for most sire breeds, regardless of end point. The AI Charolais- and CU Charolais-sired steers tended to have the highest percentages of carcasses grading USDA Standard at all end points. None of the CU Gelbvieh carcasses graded USDA Standard, and CU Pinzgauer had USDA Standard carcasses only at the constant marbling end point.

The adjustment of data from Piedmontese progeny to 23% fat trim required extrapolation beyond the available data; thus, those numbers should be interpreted with caution. The time on feed and weight required for Piedmontese progeny to reach this end point resulted in potentially unreasonable values for some traits.

The AI Charolais was the heaviest at constant age and thus the fastest growing sire breed. Longhorn and Galloway sire breeds had the slowest growth rate. Piedmontese followed by AI Charolais sire breeds were the leanest and most muscular at constant carcass weight. The AI and CU HA and Shorthorn sire breeds were the earliest maturing; they required the fewest days on feed to reach the 23% fat trim end point. There was considerable variation in growth of various fat depots (subcutaneous, marbling, and KPH), even at the different fat end points. Adjusting data to fatness end points (fat thickness, marbling, or fat trim percentage) had a greater impact on breed rankings than adjusting data to the weight-constant end point, particularly for fatness traits. Adjusting the data to 23% fat trim had the greatest effect on breed rankings.

Other studies have reported that Charolais-sired steers (Koch et al., 1976) and Gelbvieh-sired steers (Koch et al., 1979) produced heavier carcasses with less fat thickness, greater longissimus area, and lower marbling score than HA-sired steers when adjusted to an age-constant end point. Griffin et al. (1985) found that as percentage of Charolais breeding increased, carcass weight and longissimus area increased, and fat thickness and marbling score decreased with

Table 3. Least squares means for carcass traits adjusted to a common age, carcass weight, fat thickness, marbling, or fat trim percentage[a]

Trait, μ ± SEM, b1, b2[b]	Sire breed[c], LSD[d]	End point: Age (426 d)	Carcass wt (324 kg)	Fat thickness (1.2 cm)	Marbling (Small[00])	Fat trim (23%)
Days on feed	AI HA	—	256	238	220	226
μ = 272	CU HA	—	276	253	198	237
SD = 28	AI Charolais	—	237	324	254	315
	CU Charolais	—	254	293	293	310
	CU Gelbvieh	—	259	312	270	320
	CU Pinzgauer	—	271	293	220	281
	Shorthorn	—	256	271	180	230
	Galloway	—	297	271	243	271
	Longhorn	—	330	315	249	274
	Nellore	—	260	268	293	266
	Piedmontese	—	267	354	279	409
	Salers	—	256	301	270	295
Live weight, kg	AI HA	543	524	503	482	489
μ = 522 ± 1	CU HA	522	527	501	438	483
b1 = 1.0136 ± .12	AI Charolais	573	530	637	550	626
b2 = 1.1276 ± .056	CU Charolais	548	527	574	573	593
	CU Gelbvieh	541	526	588	538	597
	CU Pinzgauer	531	529	555	472	541
	Shorthorn	545	526	544	437	495
	Galloway	489	516	489	458	488
	Longhorn	458	516	501	436	460
	Nellore	520	506	516	544	513
	Piedmontese	515	509	606	523	668
	Salers	541	523	575	540	568
	LSD	16	17	17	17	18
Hot carcass weight, kg	AI HA	338	—	309	293	298
μ = 324 ± 1	CU HA	321	—	305	261	293
b1 = .69511 ± .079	AI Charolais	355	—	402	339	393
b2 = .81721 ± .037	CU Charolais	339	—	357	357	372
	CU Gelbvieh	335	—	369	333	376
	CU Pinzgauer	325	—	343	283	332
	Shorthorn	338	—	337	259	302
	Galloway	304	—	304	282	304
	Longhorn	283	—	313	266	284
	Nellore	335	—	331	352	329
	Piedmontese	328	—	396	334	442
	Salers	337	—	362	336	357
	LSD	10	—	11	11	11
Dressing percentage	AI HA	62.16	61.80	61.41	61.01	61.14
μ = 62.05 ± .06	CU HA	61.32	61.41	60.91	59.70	60.57
b1 = .01185 ± .0050	AI Charolais	61.95	61.18	63.10	61.55	62.89
b2 = .02217 ± .0023	CU Charolais	61.73	61.34	62.20	62.19	62.56
	CU Gelbvieh	61.86	61.57	62.75	61.81	62.92
	CU Pinzgauer	61.09	61.06	61.55	59.97	61.28
	Shorthorn	61.92	61.56	61.89	59.89	60.99
	Galloway	62.21	62.77	62.19	61.56	62.18
	Longhorn	61.58	62.85	62.52	61.07	61.61
	Nellore	64.26	63.98	64.17	64.74	64.12
	Piedmontese	63.69	63.57	65.54	63.86	66.80
	Salers	62.32	61.98	62.97	62.29	62.83
	LSD	.62	.66	.66	.67	.69
Adj. fat thickness, cm	AI HA	1.56	1.39	—	1.01	1.08
μ = 1.18 ± .02	CU HA	1.38	1.42	—	.68	1.06
b1 = .00402 ± .0011	AI Charolais	.89	.68	—	.78	1.14
b2 = .00805 ± .00052	CU Charolais	1.05	.92	—	1.20	1.32
	CU Gelbvieh	.94	.86	—	.93	1.25
	CU Pinzgauer	1.05	1.04	—	.68	1.11
	Shorthorn	1.21	1.08	—	.46	.86
	Galloway	1.21	1.41	—	.97	1.20
	Longhorn	.93	1.29	—	.78	.94
	Nellore	1.23	1.13	—	1.41	1.18
	Piedmontese	.77	.74	—	.81	1.49
	Salers	1.00	.90	—	.99	1.16
	LSD	.17	.18	—	.18	.19
Longissimus area, cm^2	AI HA	72.8	72.1	71.3	70.5	70.8
μ = 74.1 ± .3	CU HA	70.9	71.1	70.1	67.8	69.5
b1 = .08286 ± .019	AI Charolais	81.6	79.9	84.1	80.7	83.7
b2 = .04451 ± .0090	CU Charolais	76.7	75.9	77.7	77.7	78.5
	CU Gelbvieh	78.4	77.8	80.3	78.3	80.7
	CU Pinzgauer	74.2	74.2	75.2	71.9	74.6
	Shorthorn	72.0	71.3	72.0	68.1	70.2
	Galloway	73.4	74.5	73.3	72.1	73.3
	Longhorn	70.0	72.5	71.8	69.0	70.1
	Nellore	73.6	73.3	73.7	74.8	73.6

continued

Table 3. (*continued*)

	Piedmontese	85.8	85.5	90.0	86.2	92.9
	Salers	77.7	77.0	79.1	77.6	78.8
	LSD	3.1	3.2	3.3	3.3	3.4
KPH fat, %[e]	AI HA	2.89	2.74	2.58	2.42	2.47
μ = 2.91 ± .02	CU HA	2.78	2.82	2.62	2.14	2.48
b1 = .00373 ± .0017	AI Charolais	3.00	2.68	3.49	2.84	3.40
b2 = .00908 ± .00077	CU Charolais	2.98	2.82	3.18	3.17	3.33
	CU Gelbvieh	2.86	2.74	3.21	2.84	3.28
	CU Pinzgauer	3.03	3.02	3.23	2.55	3.11
	Shorthorn	3.07	2.91	3.06	2.20	2.67
	Galloway	2.83	3.05	2.82	2.57	2.82
	Longhorn	3.10	3.66	3.51	2.88	3.12
	Nellore	3.12	3.00	3.08	3.32	3.06
	Piedmontese	2.70	2.65	3.38	2.76	3.84
	Salers	3.05	2.91	3.33	3.04	3.27
	LSD	.23	.24	.25	.25	.26
Yield grade	AI HA	3.84	3.57	3.27	2.96	3.07
μ = 3.28 ± .03	CU HA	3.58	3.64	3.28	2.42	3.04
b1 = .00641 ± .0017	AI Charolais	2.90	2.46	3.56	2.67	3.44
b2 = .01439 ± .00078	CU Charolais	3.16	2.92	3.46	3.45	3.68
	CU Gelbvieh	2.91	2.75	3.42	2.88	3.52
	CU Pinzgauer	3.18	3.16	3.48	2.47	3.30
	Shorthorn	3.56	3.31	3.54	2.13	2.90
	Galloway	3.16	3.51	3.15	2.76	3.15
	Longhorn	2.93	3.67	3.48	2.64	2.95
	Nellore	3.48	3.29	3.42	3.79	3.38
	Piedmontese	2.29	2.24	3.11	2.37	3.66
	Salers	3.07	2.86	3.46	3.05	3.37
	LSD	.28	.29	.29	.30	.31
Marbling[f]	AI HA	527.8	519.2	509.6	—	503.3
μ = 515.8 ± 2.7	CU HA	540.6	542.8	530.3	—	521.8
b1 = .00390 ± .0017	AI Charolais	509.3	491.5	536.0	—	531.3
b2 = .00521 ± .00078	CU Charolais	489.6	480.9	500.2	—	508.3
	CU Gelbvieh	501.1	494.6	521.5	—	525.5
	CU Pinzgauer	527.4	526.7	538.8	—	532.2
	Shorthorn	551.2	542.2	550.5	—	527.7
	Galloway	515.2	528.4	514.8	—	514.6
	Longhorn	511.8	541.9	534.1	—	512.6
	Nellore	489.7	483.6	487.8	—	486.7
	Piedmontese	496.4	493.7	537.2	—	564.9
	Salers	500.7	492.8	515.4	—	512.2
	LSD	27.2	28.6	28.8	—	30.2
USDA Choice, %[g]	AI HA	74	69	64	—	60
μ = 62 ± 2	CU HA	77	78	71	—	66
b1 = .15808 ± .12	AI Charolais	63	54	77	—	75
b2 = .26418 ± .058	CU Charolais	44	41	48	—	51
	CU Gelbvieh	48	45	56	—	58
	CU Pinzgauer	65	64	71	—	67
	Shorthorn	78	73	78	—	64
	Galloway	62	69	62	—	62
	Longhorn	60	75	71	—	61
	Nellore	48	45	47	—	46
	Piedmontese	46	45	62	—	73
	Salers	48	45	54	—	53
	LSD	17	18	18	—	19
USDA Standard, %[h]	AI HA	1.0	2.0	3.2	4.4	4.0
μ = 2.4 ± .5	CU HA	3.0	1.0	2.4	6.0	3.4
b1 = .02161 ± .04	AI Charolais	8.9	10.9	5.8	9.1	6.3
b2 = .06354 ± .02	CU Charolais	5.7	6.8	4.4	4.5	3.4
	CU Gelbvieh	.0	.0	.0	.0	.0
	CU Pinzgauer	.0	.0	.0	3.2	.0
	Shorthorn	.4	1.4	.5	6.3	3.1
	Galloway	1.9	.3	2.0	3.8	2.0
	Longhorn	1.4	.0	.0	2.9	1.3
	Nellore	2.0	2.8	2.3	.8	2.4
	Piedmontese	5.6	5.9	.6	5.2	.0
	Salers	2.0	3.0	.1	2.0	.5
	LSD	5.4	5.5	5.6	5.6	5.7

[a]End points represent the overall mean for that trait in this experiment.

[b]b1 = regression coefficient for weaning age, b2 = regression coefficient for days on feed.

[c]HA = F_1 Hereford × Angus and Angus × Hereford crosses (purebred Hereford and Angus were not included to avoid confounding sire breed effects with heterosis effects). These Hereford and Angus sires are "new" (born 1982–84) relative to the original Hereford and Angus sires (born 1963–70) used in Cycles I–III of the Germplasm Evaluation Program. Clean-up (CU) sires also represent "new" sires, but have not had the benefit of as intensive a selection as the AI sires; thus, data from their progeny were reported separately.

[d]LSD = least significant difference among means ($P < .05$).

[e]Estimated percentage of hot carcass weight as kidney, pelvic, and heart fat.

[f]400 = Slight^{00}, 500 = Small^{00}.

[g]Percentage of carcasses grading USDA Choice or higher.

[h]Percentage of carcasses grading USDA Standard.

constant time on feed. Koch et al. (1982b) reported that Pinzgauer-sired steers had lower dressing percentage and less fat thickness but longissimus area and marbling score similar to that of HA-sired steers when adjusted to an age-constant end point. However, Crouse et al. (1989) found that Pinzgauer-cross steers had larger longissimus area, lower marbling score, and lower fat thickness than HA-sired steers when adjusted to an age-constant end point. Gregory et al. (1994a,b) reported that differences in carcass and meat traits among purebred Hereford, Angus, Charolais, Gelbvieh, and Pinzgauer from breeding similar to that of breeds in our study were similar (although generally of twice the magnitude, as expected for purebred vs top-cross contrasts) to those reported in our study when adjusted to an age-constant end point. However, they reported that purebred Gelbvieh steers had larger longissimus areas and less tender longissimus than purebred Charolais steers, whereas the opposite was found in the F_1 steers in this study. Tatum et al. (1990) reported that F_1 Piedmontese steers had greater dressing percentage and longissimus area and less fat thickness than F_1 Gelbvieh and Red Angus steers when adjusted to an age-constant end point. They also reported that both Piedmontese and Gelbvieh steers had lower marbling scores than Red Angus steers. Adams et al. (1982) reported that Longhorn steers had lighter carcasses than Hereford, Angus, or Holstein-cross cattle when fed to a USDA Choice quality grade end point.

Koch et al. (1982b) reported that Brahman- and Sahiwal-cross steers had lower marbling scores than HA-cross steers but similar carcass weights, longissimus areas, and fat thicknesses. In addition, Brahman-sired steers produced carcasses with higher dressing percentage than did HA-cross steers. Deviations of Nellore-crosses from $H \times A$ in these carcass traits were similar to deviations of Brahman- and Sahiwal-cross from $H \times A$ in a previous cycle of our GPE project (Koch et al., 1982b).

Time on Feed. Based on the regressions of days fed, each 30 d of additional time on feed resulted in an additional 24 kg of hot carcass weight, .24 cm of adjusted fat thickness, .4 increased USDA yield grade (.9% lower yield), 7.8% more USDA Choice carcasses, .29 kg lower longissimus shear force, .04 higher tenderness rating, and .08 and .03 higher juiciness and beef flavor intensity ratings, respectively. Thus, each additional 30 d on feed resulted in a few more USDA Choice carcasses that were slightly heavier but yielded less saleable product that was only very slightly more tender, juicy, and flavorful.

Longissimus Proximate Composition

Chemical composition of raw longissimus thoracis adjusted to 426 d of age indicated that AI HA-, CU HA-, and Shorthorn-sired steers had the highest percentages of lipid and correspondingly lowest percentages of moisture, whereas Piedmontese-, CU Gelbvieh-, CU Charolais-, Nellore-, Salers-, AI Charolais-, and Longhorn-sired steers had the lowest percentages of lipid and the highest percentages of moisture (Table 4). No sire breed differences of practical importance in protein content were detected in raw or cooked muscle. Chemical composition of the cooked longissimus thoracis indicated that Shorthorn-, Galloway-, CU HA-, and CU Pinzgauer-sired steers had higher percentages of lipid and lower percentages of moisture than Piedmontese-, CU Charolais-, and Nellore-sired steers. Cooking losses, primarily of moisture, resulted in lipid contents of about 5 to 6.5% and protein content of 32 to 33% in the cooked longissimus thoracis.

Palatability Traits

Nellore-sired steers produced longissimus with the highest shear force (least tender), and CU Pinzgauer- and Piedmontese-sired steers tended to have longissimus with the lowest shear force values, regardless of end point (Table 5). At age- and weight-constant end points, Salers- and AI Charolais-sired steers also had longissimus among the highest in shear force. Salers- and Shorthorn-sired steers also had longissimus among the highest in shear force at fat thickness, marbling, and fat trim end points, but AI Charolais-sired steers had longissimus that was intermediate in shear force at these three end points.

Trained sensory panel tenderness ratings and shear force values indicated similar relative longissimus tenderness mean differences among sire-breeds ($r = –.92$). Piedmontese- and CU Pinzgauer-sired steers tended to produce the highest and Nellore-sired steers the lowest longissimus tenderness ratings, regardless of end point. Longissimus steaks from Nellore-sired steers were less juicy than those from most other breeds, although the magnitude of this difference probably is not of practical importance. Some differences among sire breeds were detected for beef flavor intensity ratings; however, the magnitude of the differences indicates they were of little practical importance. Adjusting the data to alternative end points had very little effect on breed differences in juiciness or beef flavor intensity ratings and only minor effects on sensory tenderness ratings.

The relatively less tender longissimus from *Bos indicus* breeds of cattle has been demonstrated previously. Numerous studies have established that the longissimus from Brahman cattle is less tender than meat from *Bos taurus* breeds (Damon et al., 1960; Carpenter et al., 1961; Ramsey et al., 1963; Carroll et al., 1964; Luckett et al., 1975; Peacock et al., 1982; McKeith et al., 1985; Crouse et al., 1987). Koch et al. (1982b) and Crouse et al. (1987) reported that meat from F_1 Brahman or Sahiwal crosses was less tender than meat from Hereford-Angus F_1

Table 4. Effect of sire breed on least squares means for chemical composition of raw and cooked longissimus thoracis adjusted to 426 days of age

	Raw			Cooked		
Sire breed[a]	Lipid, %	Moisture, %	Protein, %[b]	Lipid, %	Moisture, %	Protein, %[b]
μ	4.6	72.8	22.6	6.0	61.4	32.6
AI HA	5.3	72.4	22.3	6.2	61.7	32.1
CU HA	5.4	72.1	22.5	6.4	60.5	33.1
AI Charolais	4.2	73.0	22.8	5.8	61.7	32.5
CU Charolais	4.0	73.3	22.8	5.2	62.3	32.5
CU Gelbvieh	4.0	73.3	22.7	5.5	61.0	33.4
CU Pinzgauer	4.6	72.7	22.7	6.4	61.2	32.5
Shorthorn	5.2	72.3	22.5	6.6	60.8	32.7
Galloway	4.7	72.8	22.5	6.5	61.2	32.3
Longhorn	4.3	73.0	22.7	5.7	61.5	32.8
Nellore	4.0	73.4	22.6	5.2	61.5	33.3
Piedmontese	3.8	73.1	23.1	5.0	62.4	32.6
Salers	4.1	73.2	22.7	5.5	61.9	32.6
LSD[c]	.5	.6	.2	1.2	1.4	1.1

[a]HA = F_1 Hereford × Angus and Angus × Hereford crosses (purebred Hereford and Angus were not included to avoid confounding sire breed effects with heterosis effects). These Hereford and Angus sires are “new” (born 1982–84) relative to the original Hereford and Angus sires (born 1963–70) used in Cycles I–III of the Germplasm Evaluation Program. Clean-up (CU) sires also represent “new” sires, but have not had the benefit of as intensive a selection as the AI sires; thus, data from their progeny were reported separately.
[b]Calculated by difference.
[c]LSD = least significant difference among means ($P < .05$).

crosses. Crouse et al. (1989) reported that meat tenderness declined linearly as percentage of Brahman or Sahiwal increased from 0 to 75%. In addition, they demonstrated that longissimus from Sahiwal was less tender than longissimus from Brahman. In agreement with our data, Norman (1982) reported that meat from Nellore cattle was less tender than meat from Charolais cattle.

Adams et al. (1982) reported that meat from Longhorn cattle was similar in palatability to meat from Hereford, Angus, British crossbred, Holstein, and three-way crossbred (1/4 Dairy, 1/4 British, and 1/2 Charolais or Maine Anjou) cattle. In agreement with our findings, Tatum et al. (1990) reported that steers sired by Piedmontese bulls produced more tender meat than steers sired by Gelbvieh bulls, but meat similar to that from steers sired by Red Angus bulls, when adjusted to either constant age or constant marbling score. In Cycle I of GPE, Koch et al. (1976) reported that longissimus from Charolais steers was intermediate for tenderness compared to that of other sire breeds. In Cycle II of GPE, Koch et al. (1979) reported that longissimus from Gelbvieh steers tended to be less tender than average. In Cycle III of GPE, Koch et al. (1982b) reported that longissimus from Pinzgauer steers tended to be more tender than average. These reports parallel the results in our study.

As was observed in Cycles I to III of GPE, little inherent genetic variation in juiciness and beef flavor intensity was detected. Variation in tenderness rating was twice that in ratings of juiciness and beef flavor intensity (CV 16.9, 8.2, and 6.0%, respectively). This occurred despite a wide range in marbling scores within most sire breeds. Thus, when variation in these two palatability traits occurs at the consumer level, it may be induced by cooking and seasoning practices.

Heritabilities and Correlation Coefficients

The range of differences among sire breed means (R) from topcross progeny estimates half of the breed differences (Table 6). Thus, R was doubled to estimate purebred genetic variation relative to within sire breed genetic (σ_g) and phenotypic (σ_p) variation. However, phenotypic variation was expressed without doubling R, thus representing F_1 progeny phenotypic variation. Heritability estimates for various carcass and palatability traits ranged from very low ($h^2 = .06$; dressing percentage) to very high ($h^2 = .76, .73$; yield grade, marbling score). Heritabilities of live and carcass weights and KPH fat percentage were relatively low and were lower than previous estimates (reviewed by Koch et al., 1982a). Fat thickness, longissimus area, marbling score, raw longissimus lipid, and yield grade heritabilities were relatively high and slightly higher than most estimates. Tenderness, as measured by Warner-Bratzler shear force and trained sensory tenderness rating, was intermediate in heritability. These values are consistent with the average of heritabilities reported in the literature (reviewed by Koch et al., 1982a). Some estimates of the heritability of tenderness (or shear force) have been higher ($h^2 = .53$; Shackelford et al., 1994) and others lower ($h^2 = .12$; Gregory et al., 1994b). In a review of results from Cycles I, II, and III of GPE, Cundiff et al. (1986) reported estimates of $2R/\sigma_g$ for a series of traits including fat thickness, KPH fat percentage, marbling, and carcass weight. Results from the present experiment were similar except for

Table 5. Least squares means for palatability traits adjusted to a common age, carcass weight, fat thickness, fat trim percentage, or marbling end point[a]

Trait μ ± SEM, b1, b2[b]	Sire breed[c], LSD[d]	End point: Age (426 d)	Carcass wt (324 kg)	Fat thickness (1.2 cm)	Marbling (Small^{00})	Fat trim (23%)
Shear force, kg	AI HA	5.60	5.75	5.92	6.08	6.03
μ = 5.81 ± .06	CU HA	5.72	5.68	5.89	6.41	6.04
b1 = –.01423 ± .0042	AI Charolais	6.11	6.45	5.59	6.29	5.68
b2 = –.00951 ± .0019	CU Charolais	5.74	5.91	5.54	5.54	5.39
	CU Gelbvieh	5.64	5.76	5.27	5.66	5.20
	CU Pinzgauer	5.09	5.10	4.91	5.52	5.01
	Shorthorn	5.90	6.06	5.91	6.79	6.31
	Galloway	5.84	5.60	5.85	6.12	5.85
	Longhorn	6.09	5.51	5.66	6.31	6.07
	Nellore	7.16	7.31	7.21	6.92	7.23
	Piedmontese	5.36	5.41	4.64	5.30	4.16
	Salers	6.32	6.48	6.02	6.33	6.09
	LSD	.60	.62	.63	.64	.66
Tenderness[e]	AI HA	4.72	4.70	4.69	4.67	4.67
μ = 4.74 ± .03	CU HA	4.77	4.77	4.75	4.69	4.73
b1 = .00177 ± .0021	AI Charolais	4.38	4.35	4.43	4.36	4.43
b2 = .00118 ± .00098	CU Charolais	4.80	4.78	4.83	4.83	4.85
	CU Gelbvieh	4.65	4.64	4.70	4.65	4.71
	CU Pinzgauer	5.06	5.06	5.08	5.00	5.07
	Shorthorn	4.71	4.69	4.70	4.60	4.66
	Galloway	4.81	4.84	4.81	4.78	4.81
	Longhorn	4.80	4.86	4.84	4.77	4.80
	Nellore	4.03	4.02	4.02	4.05	4.02
	Piedmontese	4.98	4.97	5.07	4.99	5.14
	Salers	4.48	4.46	4.51	4.48	4.50
	LSD	.31	.33	.33	.34	.35
Juiciness[f]	AI HA	5.11	5.07	5.02	4.97	4.99
μ = 5.08 ± .01	CU HA	5.07	5.08	5.02	4.87	4.98
b1 = .00094 ± .0012	AI Charolais	4.94	4.84	5.07	4.89	5.05
b2 = .00272 ± .00057	CU Charolais	5.03	4.99	5.09	5.09	5.13
	CU Gelbvieh	5.00	4.96	5.10	4.99	5.12
	CU Pinzgauer	5.14	5.14	5.20	5.00	5.17
	Shorthorn	5.12	5.08	5.12	4.87	5.01
	Galloway	5.12	5.19	5.12	5.04	5.12
	Longhorn	5.11	5.26	5.22	5.04	5.11
	Nellore	4.81	4.77	4.80	4.86	4.79
	Piedmontese	5.08	5.07	5.30	5.10	5.45
	Salers	5.00	4.95	5.07	4.99	5.06
	LSD	.15	.15	.15	.15	.15
Flavor intensity[g]	AI HA	4.81	4.80	4.78	4.76	4.77
μ = 4.78 ± .01	CU HA	4.82	4.82	4.80	4.75	4.79
b1 = .00036 ± .00081	AI Charolais	4.77	4.74	4.82	4.76	4.81
b2 = .00092 ± .00038	CU Charolais	4.78	4.77	4.80	4.80	4.82
	CU Gelbvieh	4.70	4.68	4.73	4.69	4.74
	CU Pinzgauer	4.80	4.80	4.82	4.76	4.81
	Shorthorn	4.84	4.83	4.84	4.76	4.80
	Galloway	4.84	4.86	4.83	4.81	4.83
	Longhorn	4.79	4.84	4.83	4.77	4.79
	Nellore	4.71	4.70	4.71	4.73	4.70
	Piedmontese	4.70	4.70	4.77	4.71	4.82
	Salers	4.76	4.75	4.79	4.76	4.78
	LSD	.11	.11	.11	.12	.12

[a]End points represent the overall mean for that trait in this experiment.

[b]b1 = regression coefficient for weaning age, b2 = regression coefficient for days on feed.

[c]HA = F_1 Hereford × Angus and Angus × Hereford crosses (purebred Hereford and Angus were not included to avoid confounding sire breed effects with heterosis effects). These Hereford and Angus sires are "new" (born 1982–84) relative to the original Hereford and Angus sires (born 1963–70) used in Cycles I–III of the Germplasm Evaluation Program. Clean-up (CU) sires also represent "new" sires, but have not had the benefit of as intensive a selection as the AI sires; thus, data from their progeny were reported separately.

[d]LSD = least significant difference among means (P < .05).

[e]1 = Extremely tough, 4 = slightly tough, 5 = slightly tender, 8 = extremely tender.

[f]1 = Extremely dry, 4 = slightly dry, 5 = slightly juicy, 8 = extremely juicy.

[g]1 = Extremely bland, 4 = slightly bland, 5 = slightly intense, 8 = extremely intense.

Table 6. Variation among sire breeds for carcass and palatability traits

Trait	R[a]	$h^2 \pm SE$[b]	σ_g[c]	$2R/\sigma_g$	σ_p[d]	R/σ_p
Live weight, kg	115	.21 ± .11	18.61	12.36	40.33	2.85
Hot carcass weight, kg	72	.15 ± .11	10.38	13.87	26.45	2.72
Dressing percentage	2.60	.06 ± .11	.40	13.00	1.65	1.58
Adj. fat thickness, cm	.79	.56 ± .12	.30	5.27	.40	1.98
Longissimus area, cm^2	15.8	.65 ± .13	5.62	5.62	6.95	2.25
KPH fat, %	.42	.32 ± .12	.32	2.63	.57	.74
Yield grade	1.55	.76 ± .13	.53	5.85	.61	2.54
Marbling	61.6	.73 ± .13	51.69	2.38	60.63	1.02
Raw lipid percentage	1.6	.56 ± .13	1.09	2.94	1.45	1.11
Cooked lipid percentage	1.6	NE[e]	2.01	1.59	1.79	.90
Shear force, kg	2.07	.37 ± .12	.87	4.76	1.44	1.44
Tenderness	1.03	.50 ± .12	.52	3.96	.74	1.39
Juiciness	.31	NE[e]	NE[e]	NE[e]	NE[e]	NE[e]
Beef flavor intensity	.14	.19 ± .11	.12	2.33	.27	.52

[a]R = range in sire breed means.
[b]h^2 = heritability.
[c]σ_g = genetic standard deviation.
[d]σ_p = phenotypic standard deviation.
[e]Not estimable.

carcass weight. In this study, $2R/\sigma_g$ was greater because of an unusually low estimate for heritability for carcass weight (i.e., h^2 = .15 compared to .43).

Among carcass traits, a large proportion of the genetic variation in yield grade was associated with fat thickness and longissimus area (Table 7). A very low genetic correlation between marbling and fat thickness was detected. Raw and cooked longissimus lipid percentage explained a large amount of the genetic variation in marbling. Surprisingly, cooked lipid had a stronger genetic correlation to marbling than raw lipid. Shear force had moderate to high genetic correlations to hot carcass weight, marbling score, and raw and cooked longissimus lipid, and a perfect genetic correlation to tenderness rating. However, tenderness rating was not as strongly related as shear force to carcass and longissimus lipid traits. Beef flavor intensity rating had a strong genetic correlation to shear force, tenderness rating, and fat thickness.

Generally, phenotypic correlations were not as high as genetic correlations. Moderate phenotypic correlations were detected between hot carcass weight and fat thickness, longissimus area, and yield grade. Phenotypically, marbling was strongly related only to measures of longissimus lipid. Marbling and raw longissimus lipid percentage were both highly related to phenotypic variation in cooked longissimus lipid percentage. Phenotypically, shear force and tenderness rating were strongly correlated only to each other, although both were moderately related to beef flavor intensity.

Shear Force Variation

These results and those of previously published cycles of GPE (Koch et al., 1976, 1979, 1982b) indicate that there are a few breeds that on average tend to produce more tender and a few that tend to produce less tender longissimus, but a majority are intermediate in tenderness. Perhaps more important than breed averages is to consider the distributions of shear force illustrating the amount of variation in shear force within a sire breed relative to the variation among sire breeds (Figure 1). These curves represent the least tender (Nellore) and most tender (CU Pinzgauer) sire breeds and AI HA crosses. Figure 1A indicates the amount of change that could be expected in shear force by selecting purebred Pinzgauer instead of purebred Nellore (by doubling the range in sire breed mean difference in shear force from the F_1 progeny) cattle (4.76 genetic standard deviations). Thus, variation among breeds apparently is less than the within-breed variation (6 genetic standard deviations). For F_1 progeny this same comparison results in 2.38 genetic standard deviations between Pinzgauer- and Nellore-sired progeny (Figure 1B), although only 1.43 phenotypic standard deviations are realized among Pinzgauer- and Nellore-sired progeny (Figure 1C). Thus, the realized improvement in tenderness from selecting one breed over another will be small (at most 1.44 kg; to change from half-blood Nellore to half-blood Pinzgauer). To make additional improvement within a breed requires identifying those sires (and dams) whose progeny produce more tender meat, either through progeny testing or some direct measure on the sire and dam to predict the tenderness of their progeny. Given the large variation in shear force within breeds, it seems that significant genetic change could result from selection both among and within breeds. However, among-breed differences may be more easily exploited than within-breed differences because they are more highly heritable, more easily identified, and less time is required. In addition, the

Table 7. Genetic and phenotypic correlation coefficients among carcass and palatability traits[a]

Trait	1	2	3	4	5	6	7	8	9	10
1. Hot carcass weight		.33	.39	.38	.09	.12	.14	−.09	.05	.07
2. Adj. fat thickness	.24 ± .27		−.07	.83	.14	.17	.15	.03	−.01	−.01
3. Longissimus area	.25 ± .24	−.43 ± .17		−.47	−.06	−.03	−.10	−.07	.01	.04
4. USDA yield grade	.18 ± .24	.86 ± .04	−.79 ± .21		.18	.19	.23	.02	.02	.00
5. Marbling score	−.03 ± .27	.01 ± .16	−.37 ± .15	.19 ± .14		.49	.71	−.11	.12	.09
6. Raw lipid[b]	.38 ± .28	−.06 ± .17	−.09 ± .16	.11 ± .15	.81 ± .10		.74	−.15	.16	.15
7. Cooked lipid[b]	.17 ± .51	.00 ± .21	−.16 ± .25	.13 ± .19	1.00[c] ± .06	1.00[c] ± .05		−.22	.22	.24
8. Shear force	−.47 ± .39	.33 ± .22	.14 ± .20	−.04 ± .19	−.55 ± .22	−.71 ± .27	−.51 ± .21		.71	−.37
9. Tenderness	.32 ± .30	−.14 ± .18	−.25 ± .17	.16 ± .16	.33 ± .16	.50 ± .17	.36 ± .17	−1.00 ± .46		.40
10. Beef flavor intensity	.13 ± .45	−.62 ± .34	−.25 ± .27	−.16 ± .25	.28 ± .26	.39 ± .28	.35 ± .24	−1.00[c] ± .66	.99 ± .27	

[a]Genetic correlation coefficients and their standard errors are below the diagonal; phenotypic correlation coefficients are above the diagonal.
[b]Proximate analysis of the longissimus thoracis.
[c]Values exceeded 1.00 and, thus, were set at 1.00.

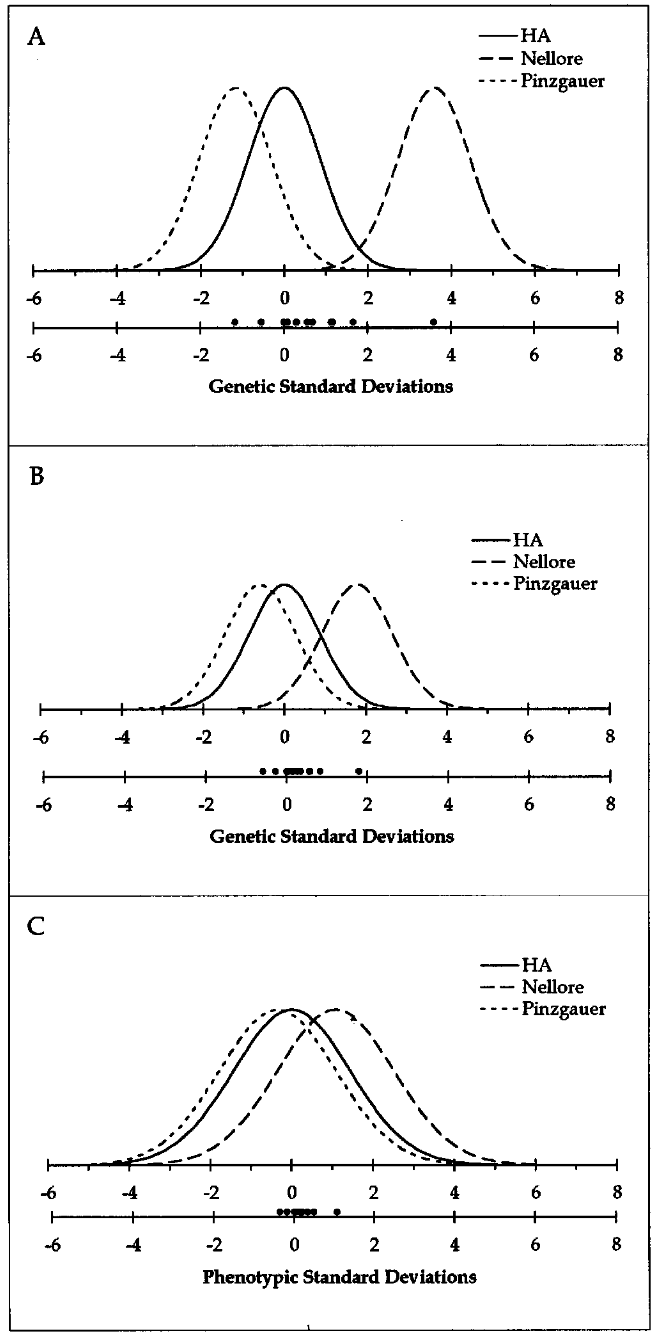

Figure 1. Genetic and phenotypic variation among and within sire breeds for Warner-Bratzler shear force. Curves for CU Pinzgauer (lowest mean shear force), Nellore (highest mean shear force), and AI Hereford and Angus reciprocal crosses (HA) are shown. HA was set to zero. Differences are expressed in standard deviation units as deviations from HA. Mean shear force deviations from HA for the other sire breeds are shown immediately below the curves. (A) Potential genetic variation among and within purebred progeny was obtained by doubling the differences in F_1 progeny. Genetic SD was .87 kg. (B) Genetic variation among and within sire breeds of F_1 progeny. Genetic SD was .87 kg. (C) Phenotypic variation among and within sire breeds of F_1 progeny. Phenotypic SD was 1.44 kg.

great impact of environmental factors on meat tenderness must be considered in attempts to improve meat tenderness. Certainly, postmortem variables must be standardized as much as possible in assessing and selecting for meat tenderness.

Implications

Large differences in carcass and meat palatability traits exist among and within cattle sire breeds. Selection of sire breed and end point of production are critical in order for producers to successfully target carcass and longissimus characteristics. No one sire breed excels in all economically important traits; however, of the sire breeds evaluated for production of terminal F_1 crosses out of Angus and Hereford cows, Piedmontese provided the greatest opportunity to produce lean, tender meat.

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